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THE IMPLICATIONS OF ALTERNATIVE AVIATION FUELS ON AIRBASE AIR QUALITY

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HAROLD A. SCOTT, JR.
ENVIRONICS DIVISION
ASSESSMENT TECHNOLOGY AND ENERGY BRANCH

LEVEL II

AUGUST 1980

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Aircraft alternative fuel emission factors from turbine engine combustor performance tests are integrated into the Air Quality Assessment Model (AQAM) to predict the air quality impact of alternative fuels use in the vicinity of Air Force bases. AQAM computes the alternative fuel emission factors from fuel property inputs, enabling the model to predict concentrations for any proposed alternative fuel blend. In addition to aircraft alternative fuel emissions calculations, AQAM was modified to calculate alternative fuel handling and breathing loss emissions from the fuel properties. Using AQAM with two aircraft

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engine models, the aircraft alternative fuel annual emissions and resulting short-term pollutant concentrations are computed for a typical Air Force base. The analysis indicates that alternative fuel emissions cause a slight increase in pollution concentrations when compared with the baseline JP-4 fuel. A reduction of evaporative hydrocarbon emissions is predicted due to the alternative fuels' lower volatility in comparison with JP-4.

PREFACE

This final report was prepared by HQ Air Force Engineering and Services Center/RDVA, Tyndall AFB, Florida. This work was accomplished under Job Order Number 21035A36; Captain Harold A. Scott, Jr., was the project officer.

A methodology is developed using Air Quality Assessment Model (AQAM) program to predict the impact of alternative jet fuels on base ambient air quality. The methodology has been designed to compile and analyze pollution measurements from the ongoing alternative fuel turbine engine performance test. The methodology and techniques assessment structure can be updated as new data become available. The alternative fuel assessment preprocessor program is on-line at the Air Force Engineering and Services Center/ACB, Tyndall AFB, Florida.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public and foreign nations.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

The USAF is investigating liquid hydrocarbon jet fuels produced from domestic sources other than unreliable and dwindling worldwide petroleum reserves. This alternative fuel program is in response to escalating fuel costs and increasing difficulties obtaining jet fuel refined from crude oil. Extensive turbine engine performance tests are being conducted with proposed jet fuels and fuel blends derived from coal, shale oil, tar sands, and other alternative sources. Future alternative fuel specifications for USAF aircraft turbine engines will be established from test results. A major concern surrounding the implementation of these alternative fuels is the environment impact on air quality. For this reason, emission exhaust measurements are being conducted during the performance tests.

The purpose of this study is to develop an air quality assessment methodology to predict the impact of proposed alternative aviation fuels on air base air quality from engine emission data obtained during the performance tests. The Air Quality Assessment Model (AQAM) is modified to predict aircraft and base emissions and pollutant concentrations using the fuel blend characteristics and the combustor emission test data. The modified AQAM program is designed to evaluate proposed fuel specification impacts on air quality relative to the five major regulated pollutants. F-4E, F-15 and F-16 aircraft operations emissions (for which engine emission data were available) are predicted by AQAM for the alternative fuels and correlated with the fuel properties. A typical base having these aircraft is used to predict the preliminary impact that these fuels will have on air quality in the base vicinity. The base AQAM impact analysis includes hydrocarbon tradeoff study to determine evaporative hydrocarbon emission reductions obtained from fuels with lower volatility. Predicted worst case pollution concentrations are also analyzed to determine the effect of alternative fuel base operations on air quality.

SECTION II

BACKGROUND

Current USAF operations use approximately 250,000 barrels of aviation fuel per day - about 50 percent of the Department of Defense (DOD) fuel usage. JP-4 is the primary fuel being used in Air Force jet aircraft. Fuel specifications for JP-4 were developed more than 25 years ago when crude oil was inexpensive and supplies plentiful. However, in the last 6 years, crude oil prices have increased tenfold and supplies are limited (Reference 1). Continuing crude oil shortages could jeopardize DOD operations.

As part of this alternative fuel program, the USAF is investigating the possibility of broadening the current JP-4 specifications so that lower quality crudes and fuels from alternative energy sources (i.e., coal, oil shale and tar sands) can be used in aircraft turbine engines to ensure reliable fuel sources at the lowest possible cost. The first phase of this investigation is the test and evaluation of turbine engine combustors using different fuel blends to determine the effects of different fuel properties and characteristics on combustor performance and durability. The USAF Aero Propulsion Laboratory (AFAPL) is currently testing several aircraft turbine engine combustor classes to examine the preliminary effects of various fuel properties on engine performance. One of the major concerns in using alternative fuels is the environmental impact on air quality. Therefore, the Air Force Engineering and Services Center (AFESC), which is the focal point for USAF air quality research, funded AFAPL to measure the combustor emissions during the combustor tests and correlate the emission rates with fuel properties and characteristics.

Engine emissions alone cannot be used to determine the environmental impact of aircraft on air quality. The air quality impact can only be predicted by estimating the amount of pollutants emitted during each aircraft operation. In addition, other sources such as fuel storage tank must be included in any alternative fuel air quality impact analysis since broader fuel specifications will affect evaporative hydrocarbon emission rates. Finally, the pollution concentrations resulting from the aircraft and base emissions have to be predicted to ensure that aircraft alternative fuel operations do not violate Federal, state, and local air pollution standards. The AQAM computer program developed by Argonne National Laboratory under contract to AFESC is a complex source dispersion model which predicts both emissions and concentrations from USAF aircraft and other base sources. AQAM is currently one of the most accurate airport dipsersion models. The program can be readily adapted to predict the air quality impact of proposed alternative aviation fuels and was selected to analyze initial alternative fuel emission data.

SECTION III

DEVELOPMENT OF THE ALTERNATIVE FUEL ASSESSMENT TECHNIQUE

3.1 AIRCRAFT TURBINE ENGINE EMISSIONS

The alternative fuel turbine engine emission factors required for this study were measured during combustor rig fuel blend performance tests conducted by General Electric under contract to the USAF Aero Propulsion Laboratory (References 2 and 3). The purpose of the program was to evaluate fuel property variations on engine performance, durability, and exhaust emissions characteristics of the J79-17A and F101 combustor rigs. Ten different fuel blends of JP-4 and JP-8 fuels were used in the combustor rig tests along with JP-4, JP-8 and No. 2 Diesel. These blends were selected to represent possible fuel property variations of future petroleum distillate fractions and non-petroleum sources.

JP-4 and JP-8 fuels were the combustor rig test baseline fuels. JP-8 is the NATO aviation fuel. The JP-4 and JP-8 fuels were blended with different agents (Table 1) to obtain variations in hydrogen content, aromatic type, final boiling point, and viscosity. The No. 2 diesel fuel (DF-2) was included in the evaluation program to approximate the Experimental Referee Broad Specification (ERBS) aviation fuel (Reference 4). The ERBS fuel broad specifications were developed by NASA.

The J79 engine is a lightweight, high-thrust, axial-flow turbojet engine with variable afterburner thrust. This turbine engine powers the F-4E fighter aircraft. The engine has been in the USAF inventory since 1956. The F101 engine is a light-weight, fully-augmented turbofan. The F101 engine represents the state-of-the-art aircraft engine technology. Although the F101 engine is currently not being produced, it is similar to the turbine engine currently being used to power the F-15 and F-16 aircraft. These aircraft will be the main USAF fighters through the 1990s. For the purpose of this study, the F101 will be assumed to power the F-15 and F-16 since data are not available for their actual engine.

During the combustor rig tests, carbon monoxide (CO), total hydrocarbons (HC), oxides of nitrogen (NO_x), and smoke emissions were measured using the appropriate pollutant standard sampling techniques and methodologies. The smoke emissions were measured as smoke numbers in accordance with SAE ARP 1179 standards (Reference 5). Particulate matter (PM) emissions are calculated from the smoke numbers using relationships developed by Shaffernocker and Stanforth (Reference 6). All emission data is reported in mass of pollutants produced by burning a specific mass of fuel.

TABLE 1. FUEL CHARACTERISTICS AFFECTING COMBUSTOR EMISSIONS

Fuel No.	Fuel Components: Base Fuel	Fuel Components: Blending Agents	Hydrogen Content (Wt %)	Density at 300°K (g/cm^3)	Vapor Pressure at 300°K (kPa)	Total Sulfur (Wt %)	Relative Droplet Size (SMD/SMD_{JP-4})
1	JP-4	--	14.5	0.7527	12.04	0.04	1.00
2	JP-8	--	14.0	0.7995	2.15	0.06	1.19
3	JP-8	GMSO[1]	13.9	0.8012	1.97	0.07	1.21
4	JP-8	2040 Solvent[2]	12.0	0.8523	1.16	0.05	1.29
5	JP-8	Xylene	13.0	0.8134	1.48	0.06	1.18
6	JP-8	Xylene	12.0	0.8276	1.33	0.05	1.18
7	JP-8	2040 Solvent	13.0	0.8252	1.38	0.07	1.23
8	JP-4	2040 Solvent	12.0	0.8297	7.38	0.02	1.14
9	JP-4	2040 Solvent	13.0	0.7963	8.61	0.04	1.06
10	JP-4	Xylene	12.0	0.8080	6.17	0.03	1.09
11	JP-4	Xylene	13.0	0.7865	9.06	0.04	1.05
12	JP-4	Xylene GMSO	14.0	0.7696	10.25	0.04	1.03
13	DF-2	--	13.1	0.8372	1.59	0.18	1.40

[1] Gulf Mineral Seal Oil, predominantly a paraffinic white oil.

[2] A naphthalene concentrate (bicyclic aromatic).

The emission factors are corrected to represent full engine pollution conditions. The corrected pollutant emission factors are computed by normalizing engine operating or severity parameters with the combustor rig parameters. Predicted actual engine emissions were calculated for simulated idle, cruise, takeoff, and dash operating condition.

Emissions data were compared with fuel properties to establish a relationship between engine emissions with variations in fuel properties. Hydrogen fuel content, fuel volatility and fuel droplet size were found to be the two fuel properties which correlated with emission rates. The J79 CO, NO_x and PM emissions are increased by decreasing hydrogen fuel content. F101 NO_x emissions are also increased by lower hydrogen fuel content. The F101 CO emissions are best correlated with either relative spray droplet size or fuel volatility. Increased droplet size or volatility increases CO emissions. F101 PM and HC emissions are extremely low compared to the J79 and are not significantly affected by fuel property variations. J79 HC emissions do not correlate with the fuel properties investigated. The fuel properties used in this analysis are presented by fuel type in Table 1. Each pollutant except HC emissions were correlated with appropriate fuel property using regression analysis. The regression equation developed by General Electric (References 1 and 2) are presented in Table 2. Both the J79 and F101 emission factors can be directly calculated for various fuel properties with these regression equations. These equations will be the basis for determining aircraft emissions in the alternative fuel analysis.

TABLE 2. ALTERNATIVE FUEL REGRESSION EQUATIONS

J79	F101
CO $Y_{IDLE}=65.9\left(\frac{X}{14.5}\right)^{-0.47}$ $Y_{APPROACH}=14.8\left(\frac{X}{14.5}\right)^{-1.38}$ $Y_{MILITARY}=4.5\left(\frac{X}{14.5}\right)^{+0.20}$	CO $Y_{IDLE}=26.8+24.8(Z-1)$ $Y_{APPROACH}=2.2$ g/kg $Y_{MILITARY}=0.5$ g/kg
HC No Direct Correlation	HC No Direct Correlation
NO_x $Y_{IDLE}=2.6\left(\frac{X}{14.5}\right)^{+0.41}$ $Y_{APPROACH}=4.6\left(\frac{X}{14.5}\right)^{-0.07}$ $Y_{MILITARY}=10.8\left(\frac{X}{14.5}\right)^{-0.39}$	NO_x $Y_{IDLE}=3.1\left(\frac{X}{14.5}\right)^{-1.38}$ $Y_{APPROACH}=8.9\left(\frac{X}{14.5}\right)^{-0.86}$ $Y_{MILITARY}=25.2\left(\frac{X}{14.5}\right)^{-0.67}$
PM $Y_{MILITARY}=0.26\left(\frac{X}{14.5}\right)^{-11.6}$ $Y_{APPROACH}=0.06\left(\frac{X}{14.5}\right)^{-11.2}$ $Y_{MILITARY}=1.01\left(\frac{X}{14.5}\right)^{-6.2}$	PM All Emissions Are Less Than 0.06 g/kg
Where: X=Fuel Hydrogen Content (weight percentage) Y=Combustor Emissions (g/kg) $Z=SMD/SMD_{JP-4}$	

3.2 EVAPORATIVE HYDROCARBON EMISSIONS

Evaporative hydrocarbon emissions must be included in an alternative fuel analysis because lower fuel volatility will reduce the evaporative HC emissions during fuel handling and storage. This reduction must be considered in predicting the total impact of alternative fuels on local air quality. The American Petroleum Institute (API) empirical equations (References 7, 8, 9) predict the HC evaporative emissions. These equations compute the fuel loss due to handling and storage of liquid petroleum fuels. Evaporative emissions are calculated from many variables. Of these variables, fuel density, fuel storage constant, and vapor pressure as a function of temperature are the three variables directly related to the fuel properties. These variables have to be determined for each alternative fuel blend.

Fuel densities are measured for each fuel and fuel blend and can be directly obtained for each alternative fuel (Table 1). The storage constants have been developed for both JP-4, JP-8, and DF-2. For this analysis, the different fuel blends will be assigned the storage constant of the baseline fuel used for the blend. This is not a bad assumption since the JP-4 and DF-2 constants vary less than 15 percent for the different types of storage tanks (Reference 8).

The vapor pressure in the API equations must be calculated using the ambient temperature to compute evaporative loss estimations. Vapor pressure can be expressed in terms of absolute temperature. Figure 1 shows the log vapor pressure (psia) as a function of inverse temperature ($1/°R \times 10^3$) for several aviation fuels (Reference 10). The curves are linear. To determine the different fuel blends pressure-temperature curves, each blend's vapor pressure at 300°K ($1.85\ 1/R° \times 10^3$) is obtained from Table 1 and located on Figure 1. It is assumed that the fuel blend's curve will have the same slope as the baseline fuel of the blend. Thus, the presure-temperature line is parallel to the baseline linear curve and intersects the 300°K vapor pressure point. For example, fuel blend number 10 has a vapor pressure of 300#kPa (0.9 psia) at 300°K ($1.85\ 1/R° \times 10^3$). Fuel blend number 10 is a blend of JP-4. The pressure-temperature curve is plotted in Figure 1 as a parallel line to the JP-4 curve intersecting the 300°K point at 0.9 psia. These relationships along with other API input variables are used in this analysis to calculate air-base evaporative hydrocarbon emissions from the handling and storage of alternative fuels.

3.3 AQAM MODIFICATIONS

AQAM predicts and analyzes the air quality impact of the various fuels and fuel blends. AQAM is a complex source Gaussian dispersion computer model (Reference 11). The model considers

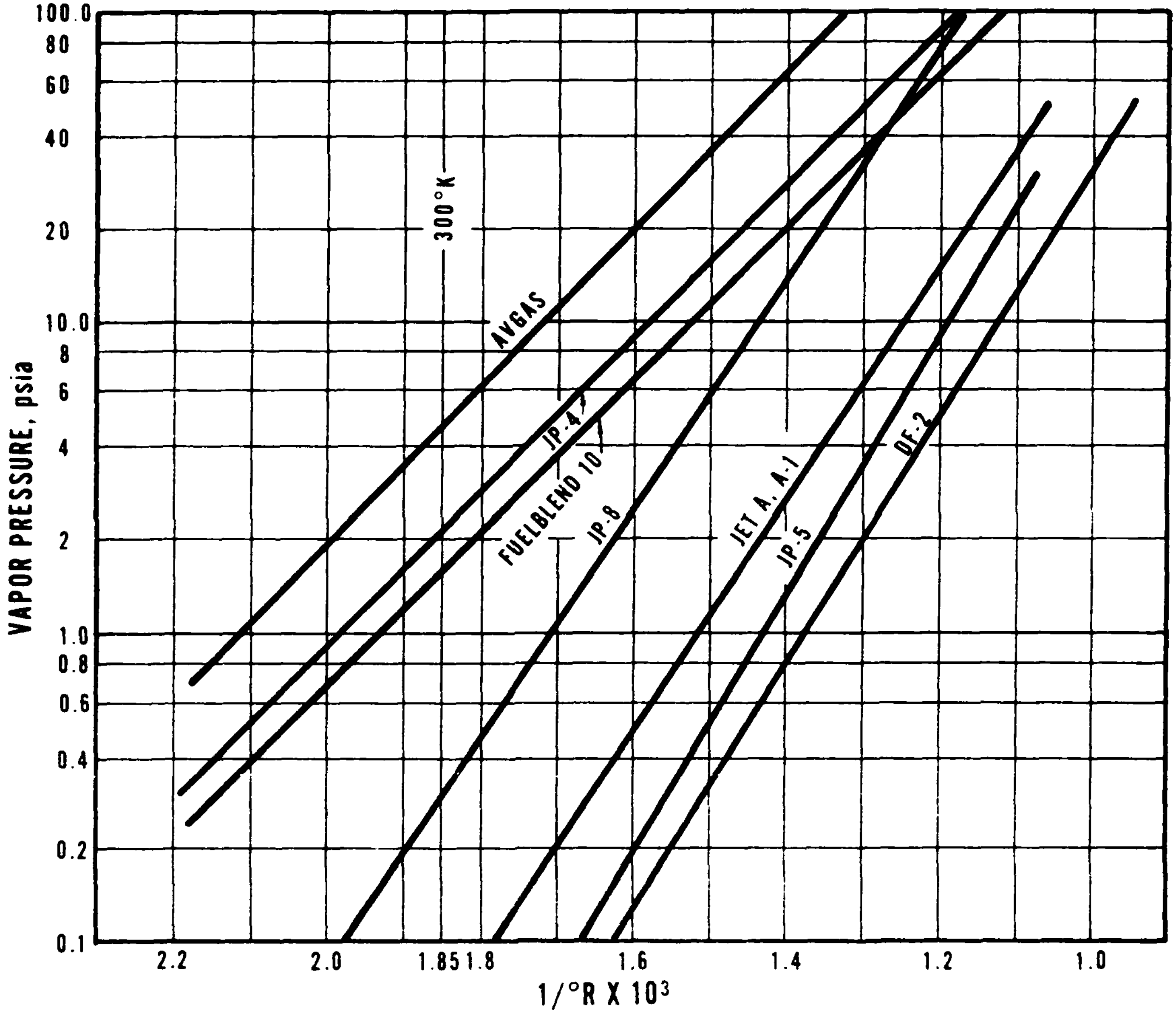

Figure 1. Fuel Vapor Pressure Versus Temperature

most air pollution sources found on USAF and Navy installations. The AQAM computer porgram has three subprograms (Figure 2): the source inventory, short term dispersion, and long term dispersion. The source inventory reads airbase source performance and activity data collected by the user. The emission factors for most of the sources are contained in the source inventory. The source inventory computes the emissions from the airbase and prints summary listing. In addition, the source inventory generates an output file. This file contains source emission rates, activity distributions and locations as point, line and area sources. Both the short-term and long-term dispersion directly access the file to calculate hourly and annual pollution concentrations in the airbase vicinity. Steady-state Gaussian dispersion models are used by AQAM to predict the CO, HC, NO_x, PM, and SO_x concentration. Nonreactive plumes are assumed. The source inventory and short-term subprograms are employed to analyze the air quality impact of the alternative fuels.

The AQAM source inventory was modified to read the fuel properties effecting both aircraft and evaporative hydrocarbon parameters. A "preprocessor" program is developed to read and process aircraft alternative fuel data. This program (Figure 3) contains the regression equations relating fuel properties to engine emissions. The program currently reads three fuel properties from the fuel parameter card (Figure 4) currently required for the J79 and F101 engines. There exists additional space for more fuel property variables on the input card. The hydrogen content, Sauter Mean Diameter (SMD) and sulfur content are found in Table I for each fuel and fuel blend. The complete combustion of sulfur to sulfur dioxide (SO_2) is assumed. A simple multiplier factor is included in the preprocessor program. This factor of 30g SO_2/kg is multiplied by the fuel sulfur content (% Weight S) to obtain the SO_2 emissions. Preprocessor program calculates the engine emission factors in g pollutants per kg fuel burn during each engine mode.

The alternative fuel blend emission factors are a direct input into the source inventory namelist. The source inventory program assigns the engine to an aircraft and computes the emissions from the specified aircraft operations. The preprocessor program will be eventually incorporated into the source inventory program. However, it is currently being kept in a "breadboard" format until the major alternative fuel engine test studies are completed and these combustor rig results are confirmed.

The evaporative emission calculation subroutines are readily adapted to variations in fuel properties. Fuel density, fuel constants, and vapor pressure are the three parameters required by the source inventory program to compute aviation fuel evaporative hydrocarbon emissions using the API procedures. These variables are on the input card to the preprocesor program

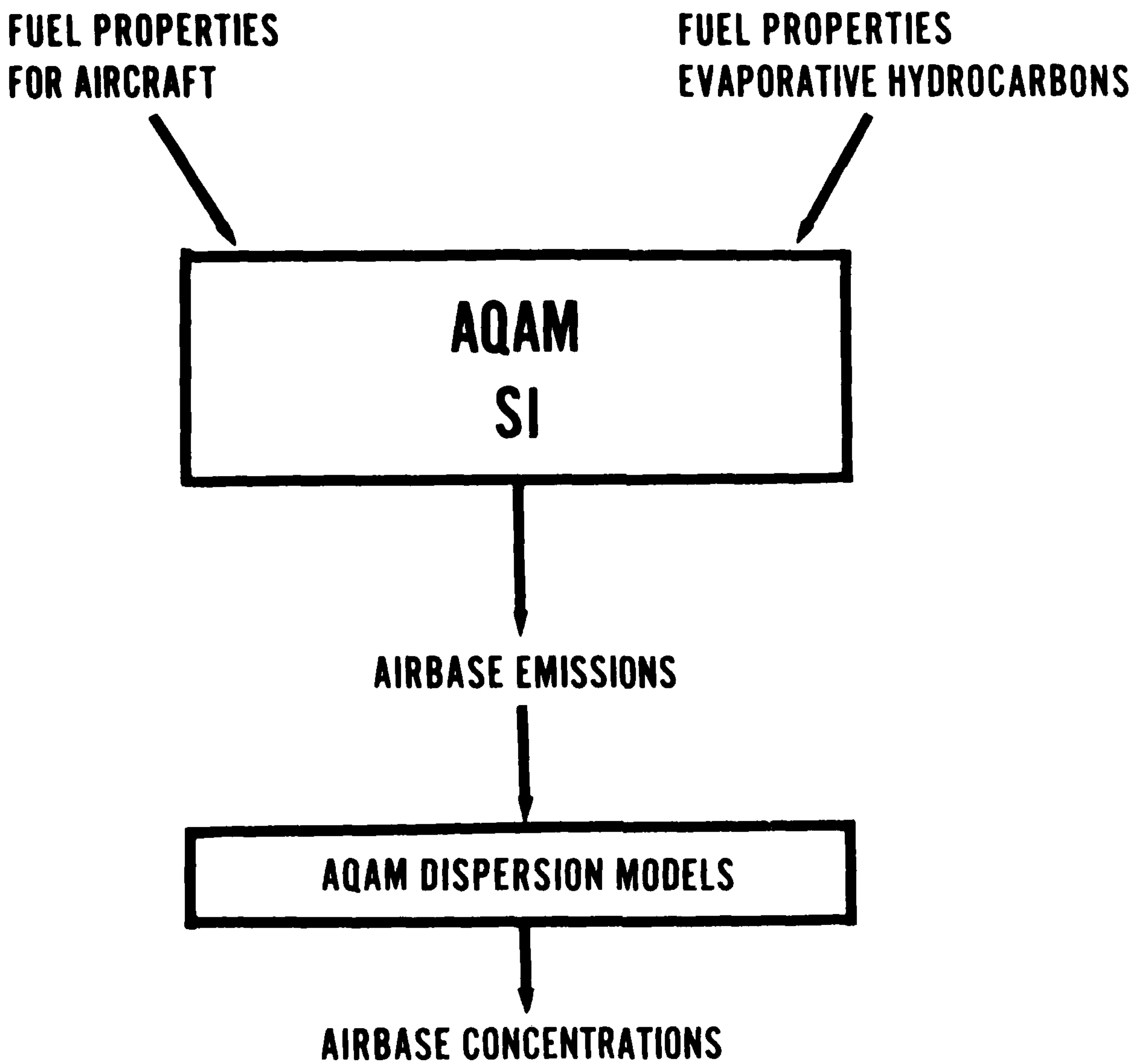

Figure 2. AQAM Flow Diagram

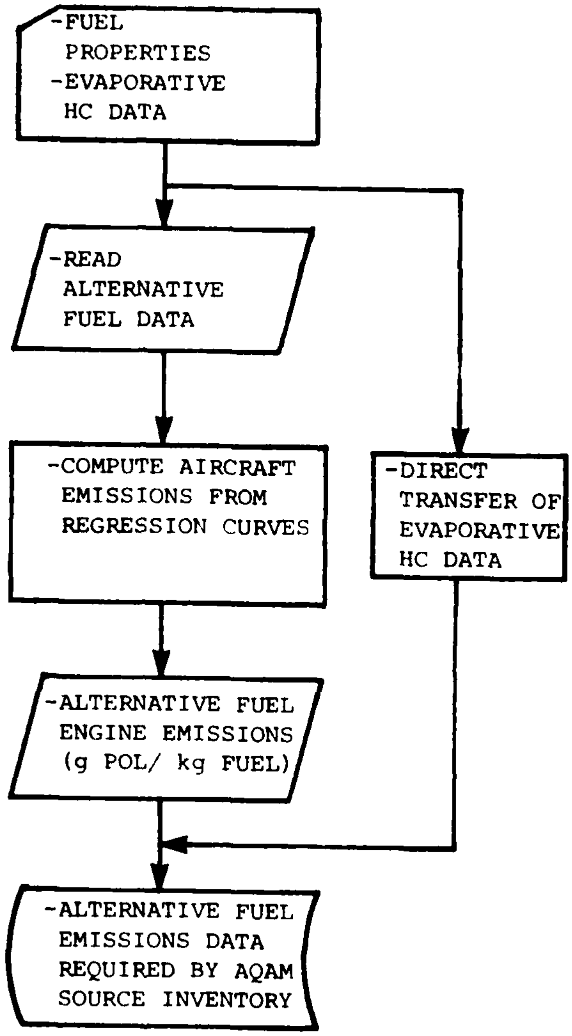

Figure 3. Preprocessor Program

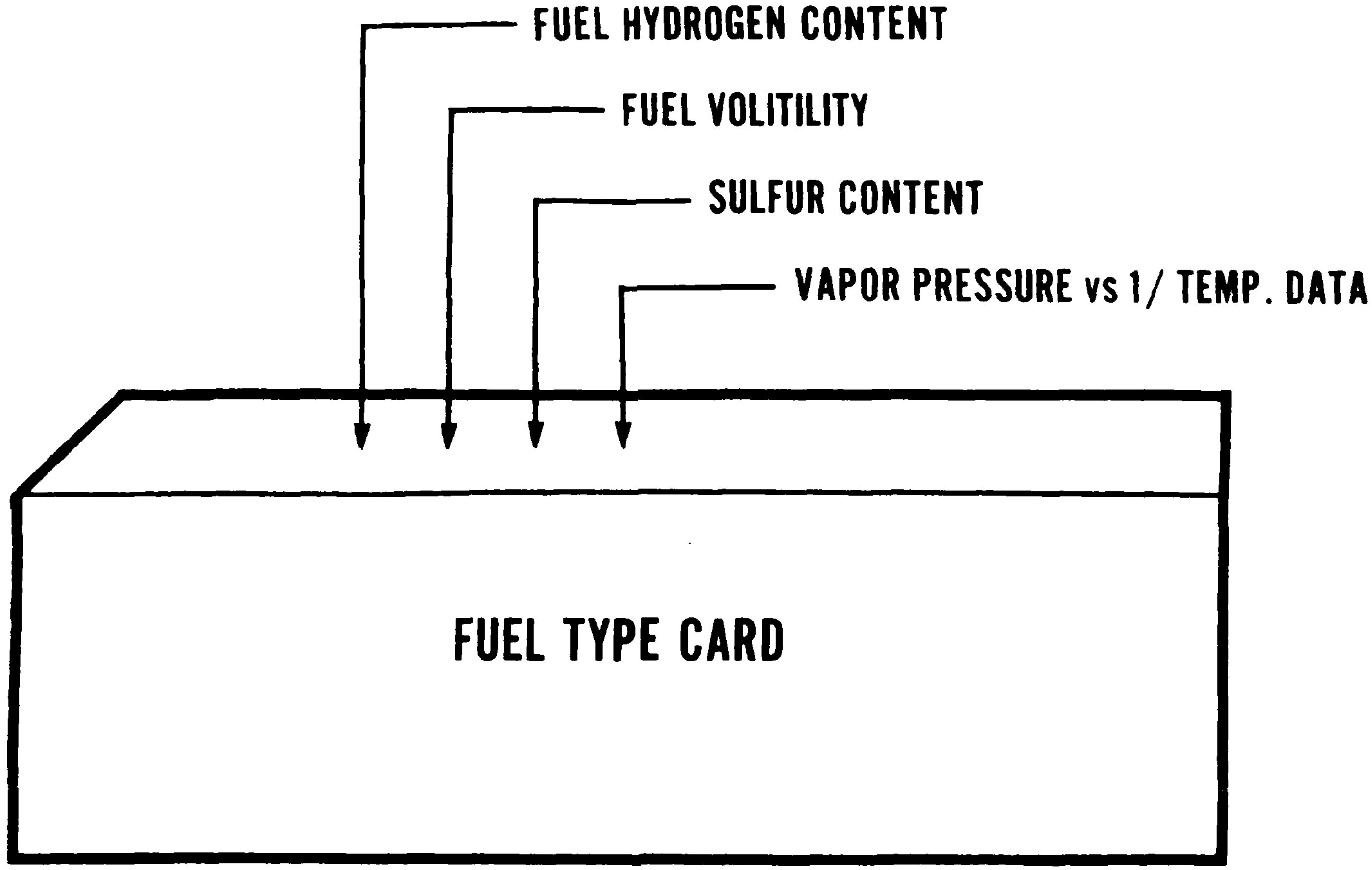

Figure 4. Input Card

(Figure 4). The fuel density is directly read and assigned to the variable FLDENS. The fuel constants or "k" values of the different storage facilities types are assumed to be the same as the baseline fuel used with the blending agents. The proper "k" values are specified by entering the baseline fuel number on the input card (Figure 4). AQAM uses the log pressure-inverse temperature relationship (Figure 1) to calculate fuel vapor pressure from the ambient temperature. The following equation is used in source inventory:

$$P = \exp\ (\alpha - \beta/T)$$

where:

P = true vapor pressure (psia)
T = temperature (°A)
α = intercept of log P vs 1/T plot
β - slope of log P vs 1/T plot

As discussed in subsection 3.2, the slope of the fuel blends is assumed to be the same as the baseline fuel slope. Therefore, for this analysis, is:

11.97 (JP-4 baseline)
14.30 (JP-8 baseline)
17.46 (DF-2)

The intercept (α) is the log of the absolute value between the baseline fuel and the fuel blend at 300°k. At 300°k, the baseline fuel pressures are:

(JP-4)
(JP-8)
(DF-2)

Once α, and β are found, the values are entered on the input card. The source inventory will calculate the emissions based on the fuel property data specified.

At present, only six input variables are needed to specify an alternative aviation fuel for an AQAM analysis. The program currently considers just two aircraft turbine engines; J79 and F101. However, the preprocessor structure will enable 50 engines to be addressed as more engines are tested. The input card is designed to include at least 16 fuel property variables. Since all the fuel properties are contained in an 80 character record, many alternative fuel AQAM analyses can be performed with just one card being required for each fuel under investigation. These modifications give the AQAM program the flexibility of assessing the airbase air quality impacts from future alternative jet fuels. The same program structure could be used for air quality analyses of other fuels such as gasoline.

SECTION IV

INITIAL ALTERNATIVE AVIATION FUEL AIR QUALITY ANALYSES

4.1 AIR QUALITY IMPACT ANALYSES

Several AQAM computer analyses are used to predict emissions and worst case air pollution concentrations resulting from alternative fuel aircraft operations. The first of the analyses investigates the emissions emitted during a typical aircraft landing and takeoff (LTO) cycle. This analysis will provide data on aircraft alternative fuel emission variations. It also provides a means of comparing different aircraft with respect to air pollution. The second analysis is an emission analysis of airbase HC. With this analysis, aircraft and evaporative HC emission variations resulting from the alternative fuel blends are predicted. In addition, alternative aviation fuel HC emissions can be compared with the entire airbase emissions. The third analysis predicts worst case air pollution concentrations for the worst case alternative fuel emissions. These worst case concentration are also presented in the Pollution Standards Index (PSI) to compare all five regulated pollutants health effects on a normalized scale. Where the emission analysis predicts the amount of pollutants being emitted in the atmosphere, the dispersion model analysis predicts the concentration of the pollutants resulting from the emissions. Predicted concentrations can be compared with standards and health effects. This comprehensive AQAM air quality analysis provides emissions, concentrations and health effects data from preliminary alternative aviation fuels engine tests.

4.2 AIRCRAFT EMISSIONS

Aircraft LTO cycle emissions are the most effective method in comparing aircraft emissions. The AQAM LTO cycle is shown in Figure 5. Each phase of the LTO cycle is programmed into AQAM for the F-4E, F-15 and F-16 aircraft. These time-in-phase operations data were determined from actual observations and are presented in Table 3. The AQAM program computes emissions for each LTO cycle phase from the appropriate aircraft operational and thrust mode emissions data. The total LTO emissions provides a complete composite of actual emissions emitted since both the high power (NO_x) and lower power (CO) emissions relative variations are included. Aircraft operational characteristics can greatly vary the LTO emission. For example, the F-4E's J79-17A afterburner (AB) and military engine mode NO_x emissions rate is only half of F-15's F101 military and AB rates. However, the F-15 LTO NO_x emissions are lower than the F-4E because the F-15 does not use the AB mode for takeoff. Thus, in a simple comparison of engine emissions, the F-15 would emit greater NO_x emissions than the F-4E. Actual aircraft LTO emissions indicate

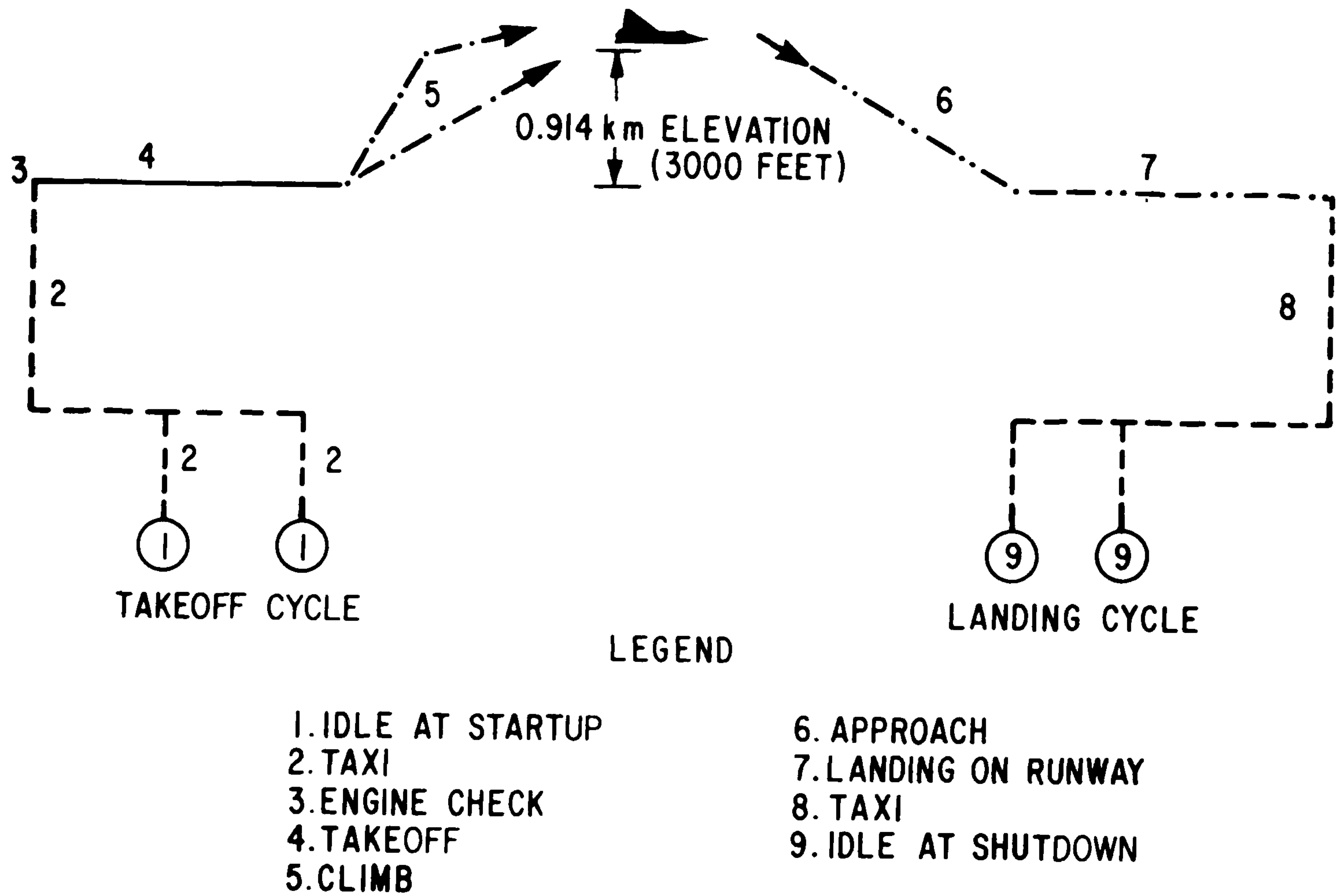

Figure 5. AQAM Landing and Takeoff Cycle

TABLE 3. AIRCRAFT LTO CYCLE PHASE TIMES

LTO PHASE	TIME IN PHASE (Minutes)		
	F-4E	F-15	F-16
1. Idle at Start Up	6.4	7.5	7.8
2. Taxi (Departure	8.8	6.6	7.2
3. Engine Check	0.8	0.1	0.3
4. Runway Roll	0.2	0.2	0.2
5. Climb	0.7	0.6	0.4
6. Approach	2.4	1.6	1.2
7. Landing on Runway	1.0	1.0	1.0
8. Tazi (Arrival)	3.1	3.4	3.8
9. Idle at Shut Down	0.4	0.2	0.1

the contrary. The F-4E, F-15, and F-16 LTO emissions were calculated for each alternative fuel blend and analyzed.

LTO emissions were compared with the fuel property related to a particular pollutant type. Results of this analysis are shown in Figures 6 through 10. HC LTO emissions are not presented since the hydrocarbon J79 engine emissions could not be directly related to a fuel characteristic. The F101 engine PM and HC were extremely low and resulted in less than 0.25 kg/LTO for all fuel blends. The coefficient of determination (r^2) is greater than 0.96 for all the regression curves. By knowing the fuel characteristic, the aircraft base emissions can be calculated and compared from the regression equations. These regression curves can be generated for other aircraft types when their alternative fuel engine emissions are measured or estimated. With the AQAM program these curves are easily developed for all major aircraft systems in the USAF inventory.

4.3 EVAPORATIVE AND BASE EMISSIONS

The base evaporative HC emissions reductions resulting from the use of less volatile aviation fuel are analyzed with the modified AQAM program. A tactical air base was selected for the study. All major base source data were programmed into the source inventory. The program simulated 50,000 annual aircraft operations. These operations represent a hypothetical F-4E, F-15 and F-16 aircraft mid-1980 mix when these fuels are proposed to be implemented. Sixty percent of the aircraft are F-15s and F-16s. Annual base emissions for each fuel blend were estimated along with HC emissions from aviation fuel storage losses and aircraft venting and spillage. Ground motor vehicles are assumed to consume gasoline refined from crude oil. Other base sources are also assumed to use their present fuels type.

The fuel storage HC breathing loss emissions reductions are analyzed with the JP-4 baseline fuel. The aircraft spillage and vent emissions are compared with the total annual aircraft hydrocarbon emissions. The total base HC emissions are estimated to determine the total base HC emission reduction. The HC tradeoff results are presented in Table 4. It should be noted that the emissions are total HC.

4.4 SHORT-TERM AIR QUALITY AND HEALTH EFFECTS

The impact of alternative fuel aircraft operations on local air quality was estimated by the AQAM short-term dispersion model. One-hour worst case aircraft pollution concentrations were predicted for a worst case fuel blend. The worst case meteorological and operational data are shown in Table 5. The aircraft LTOs and Touch and Gos in Table 5 are the maximum number that can normally be accomodated during a single hour. The worst case meteorological data represent those conditions which cause

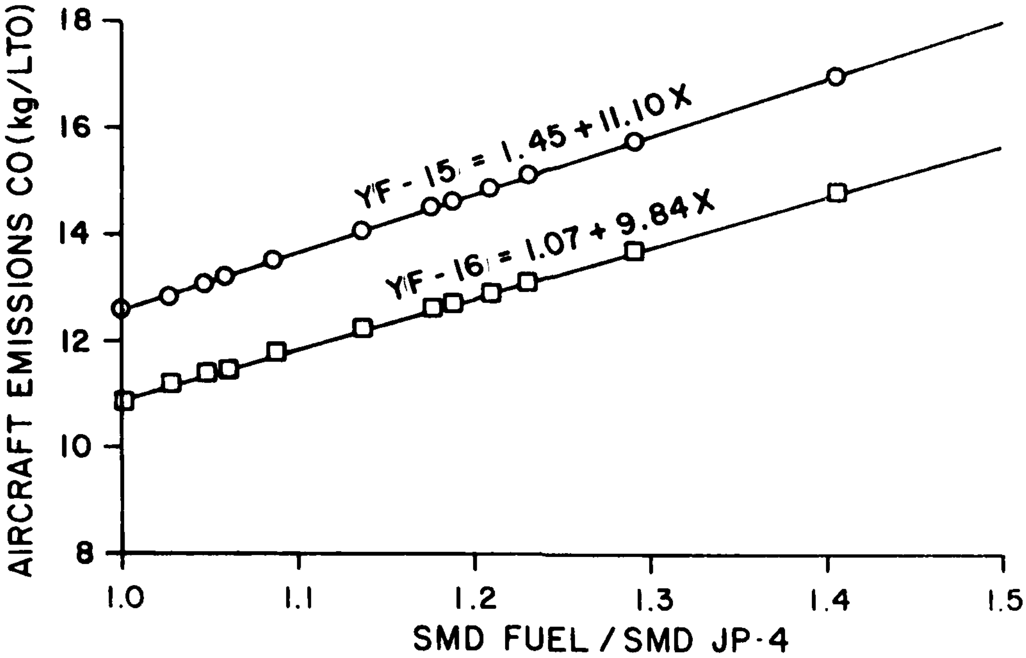

Figure 6. F-15 and F-16 CO LTO Emissions

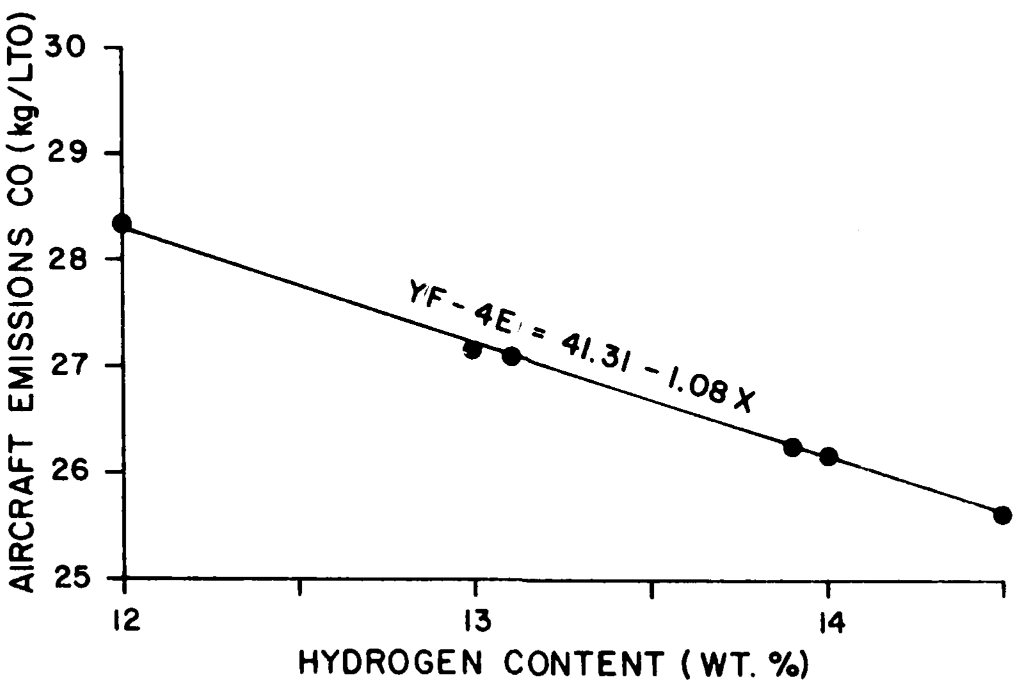

Figure 7. F-4E CO LTO Emissions

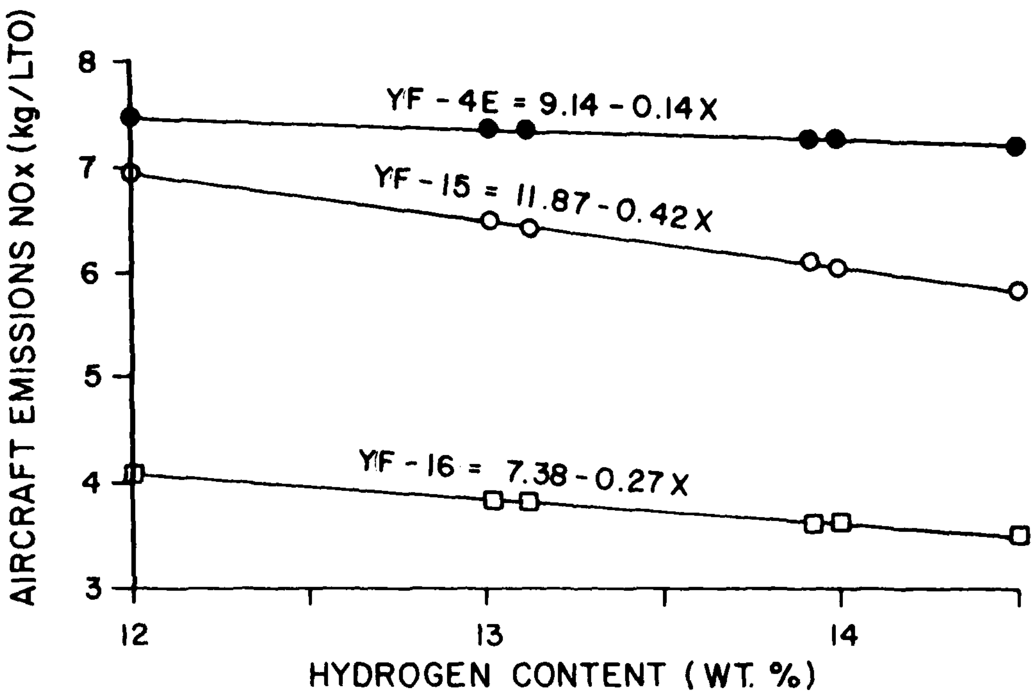

Figure 8. NO_x LTO Emissions

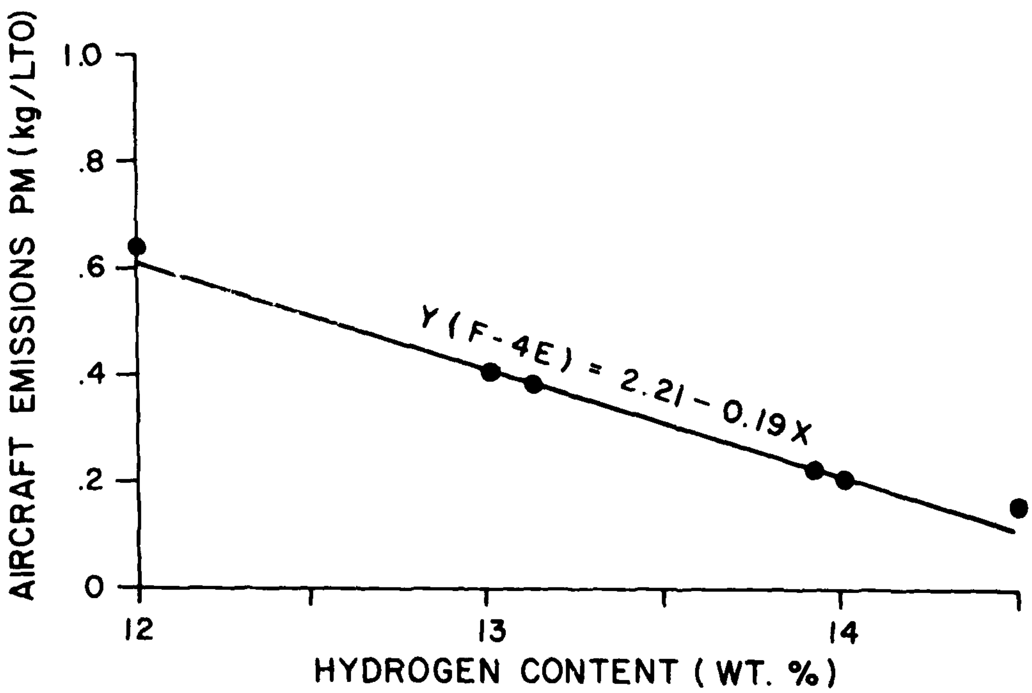

Figure 9. F-4E PM LTO Emissions

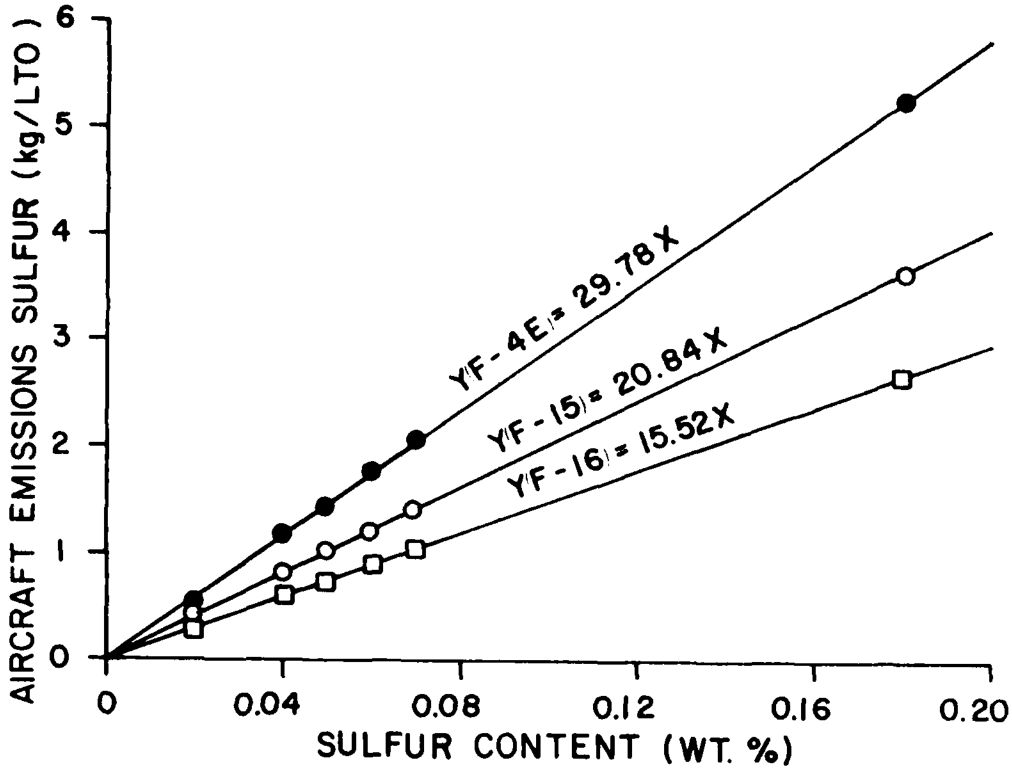

Figure 10. SO_x LTO Emissions

TABLE 4. HYDROCARBON EMISSIONS

AIRCRAFT OPERATION HYDROCARBON EMISSIONS (kg/year)

Fuel No.	Aircraft Operation Total Emissions	Aircraft Emissions	Venting and Spillage	Reduction (Increase) From JP-4
1	1.37×10^5	8.97×10^4	6.78×10^4	0%
2	1.13×10^5	8.70×10^4	2.59×10^4	18%
4	1.09×10^5	8.20×10^4	2.64×10^4	20%
8	1.43×10^5	1.08×10^5	3.51×10^4	(4%)
13	1.22×10^5	9.72×10^4	2.48×10^4	11%

FUEL HANDLING AND STORAGE HYDROCARBON EMISSIONS (kg/year)

Fuel No.	Aircraft Fuel Storage and Handling Loss	Reduction From JP-4
1	3.64×10^5	0%
2	2.47×10^5	32%
4	2.44×10^5	33%
8	2.71×10^5	26%
13	2.40×10^5	34%

TOTAL BASE HYDROCARBON EMISSIONS (kg/year)

Fuel No.	Base Hydrocarbon Emissions	Reduction From JP-4
1	1.06×10^5	0%
2	9.23×10^5	13%
4	9.18×10^5	12%
8	9.78×10^5	8%
13	9.26×10^5	13%

TABLE 5. WORST CASE CONDITIONS

METEOROLOGY

Wind Speed:	1 m/s
Mixing Height:	700 m
Stability Category:	D
Temperature:	$1^{\circ}C$

AIRCRAFT OPERATIONS DATA

Time: 0800 - 0859 hours

Aircraft Hourly Operations by Aircraft Type:

	LTO	TGO
F-4E	7	4
F-15	12	8
F-16	3	2

WORST CASE FUEL SPECIFICATIONS

Hydrogen Content (Percent Weight):	12
Relative Fuel Droplet Size (SMD/SMD_{JP-4}):	1.4
Sulfur Content (Percent Weight):	0.18

the least amount of pollutant dispersion in the base vicinity. These data were determined from base weather station observation. These worst case conditions occur during early morning hours when motor vehicle emissions are also at a peak. Annual pollution concentrations are not considered in this analysis because aircraft related annual pollutant concentrations are extremely low. Therefore, pollution concentration variation due to changes in fuel blends are too minor to make comparisons.

AQAM short-term predicted pollutant concentrations were calculated for aircraft and the base. These concentrations were predicted for a 17-km by 17-km grid surrounding the base with receptors located at 0.5 km points within the grid. The runways, taxiways, parking areas, and receptor points are shown in Figure 11. Isopleths (Figures 12, 13, 14, and 15) were created from the grid receptor concentration data.

Isopeths can give a false presentation of peak concentrations expecially with aircraft. The aircraft's plume penetration zone is very dynamic. The zone is located within the first 50 m to 150 m behind aircraft's exhaust port (Reference 12). Beyond this penetration, the plume loops and separates from the ground. This plume rise is not currently considered by AQAM's dispersion models. The model tends to never predict in this "near field" which has to be estimated to extend approximately 0.5 to 1 km from the aircraft exhaust port (Reference 13). This "near field" appears as a sharp spike on pollution concentration isopleths especially when the aircraft point source is located at a receptor point. In order to address this "near field" effect special receptors were located 0.5 and 1.0 km downwind from the aircraft parking areas and the blast area at the end of the runway (Figure 11). These receptors estimate maximum aircraft pollutant concentrations that the model can accurately predict. An average receptor was placed 2.5 km downwind of the aircraft operations areas to provide data on pollution concentrations leaving the base boundries.

A worst case alternative fuel was selected for comparison with the JP-4 baseline fuel. The fuel characteristics presented in Table 5 caused the greatest increases in both aircraft and evaporative HC emissions of the fuel blend tested. This worst case fuel represents the highest emissions from aircraft activity and greatest potential pollution concentration of all the fuels investigated. CO, HC, and NOx are the only significant pollutants found during the AQAM Maximum PM and Oxides of Sulfur SO_x (reported as SO_2) were below 3 g/m^3. The greatest CO and HC concentrations occured just below the F-4E parking area with NOx concentrations peak at the runway blast area. AQAM aircraft predictions are presented in Table 6.

PSI Index is used in this analysis to compare short-term pollutant concentration results. The PSI developed by EPA to

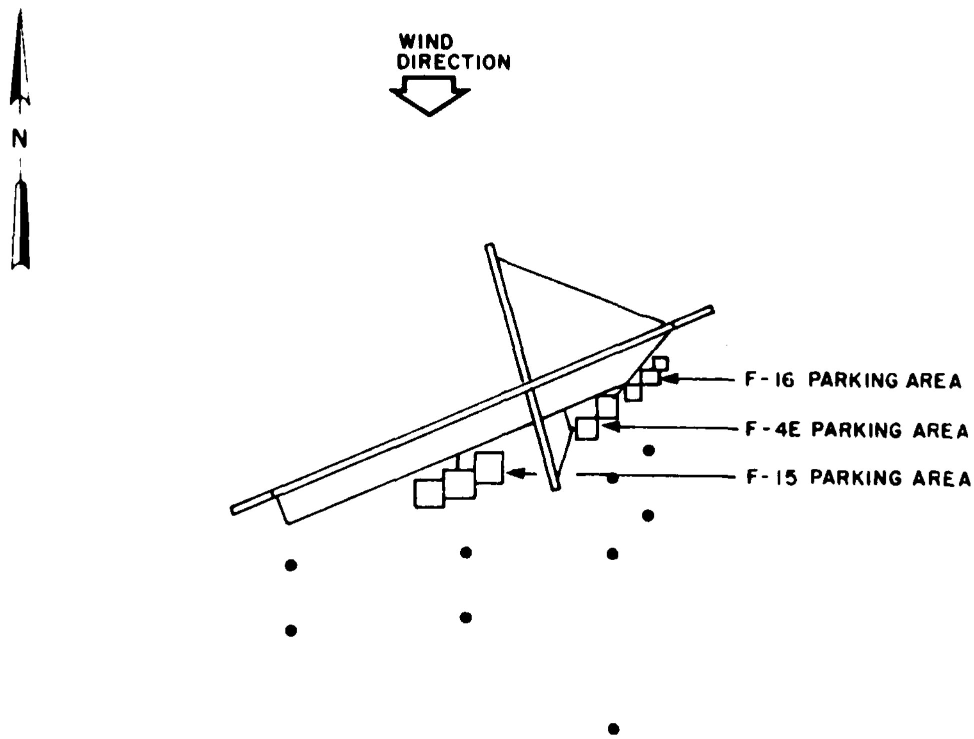

Figure 11. Runway Configuration and Receptor Locations

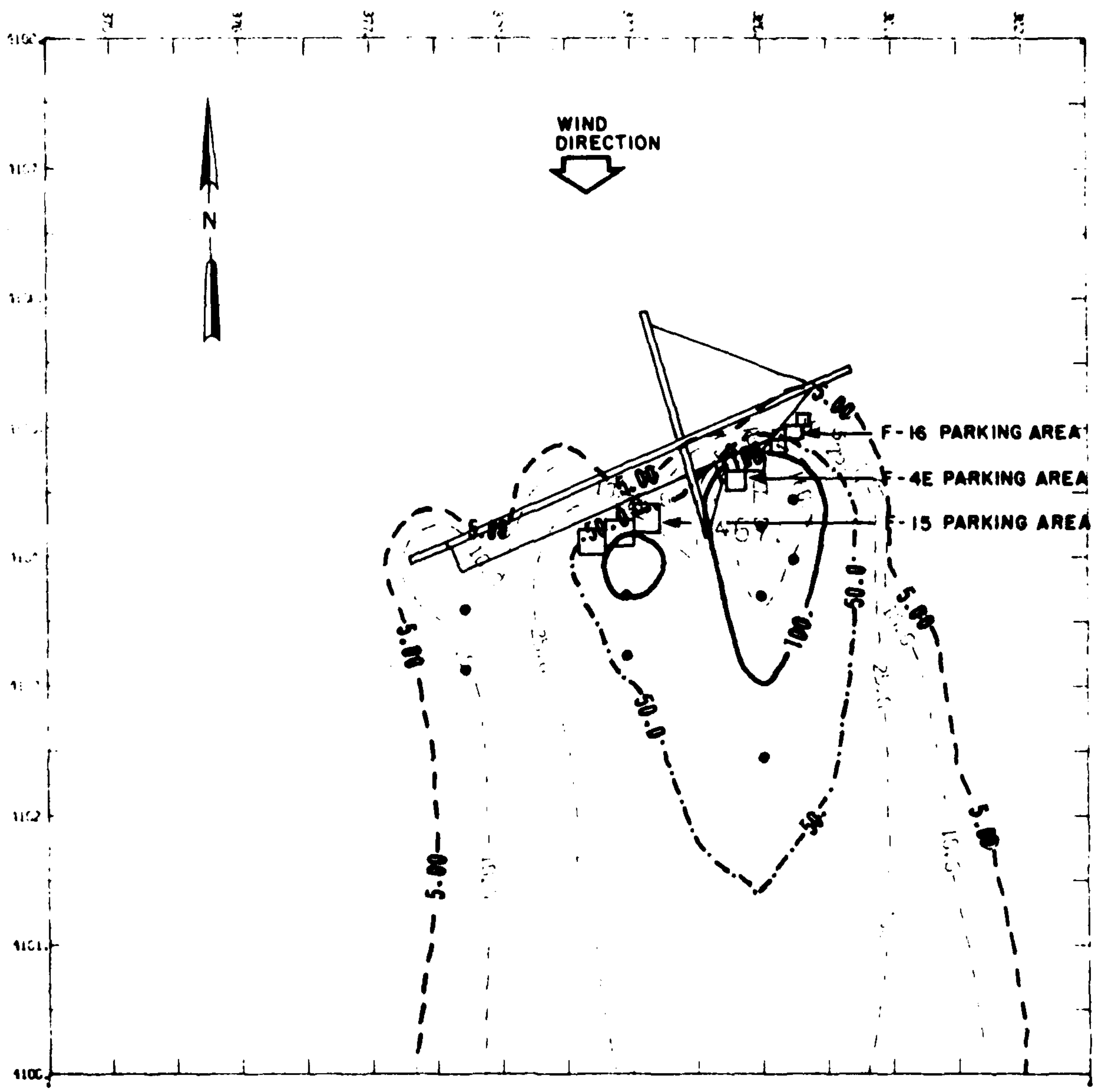

Figure 12. CO Isopleth (Aircraft)

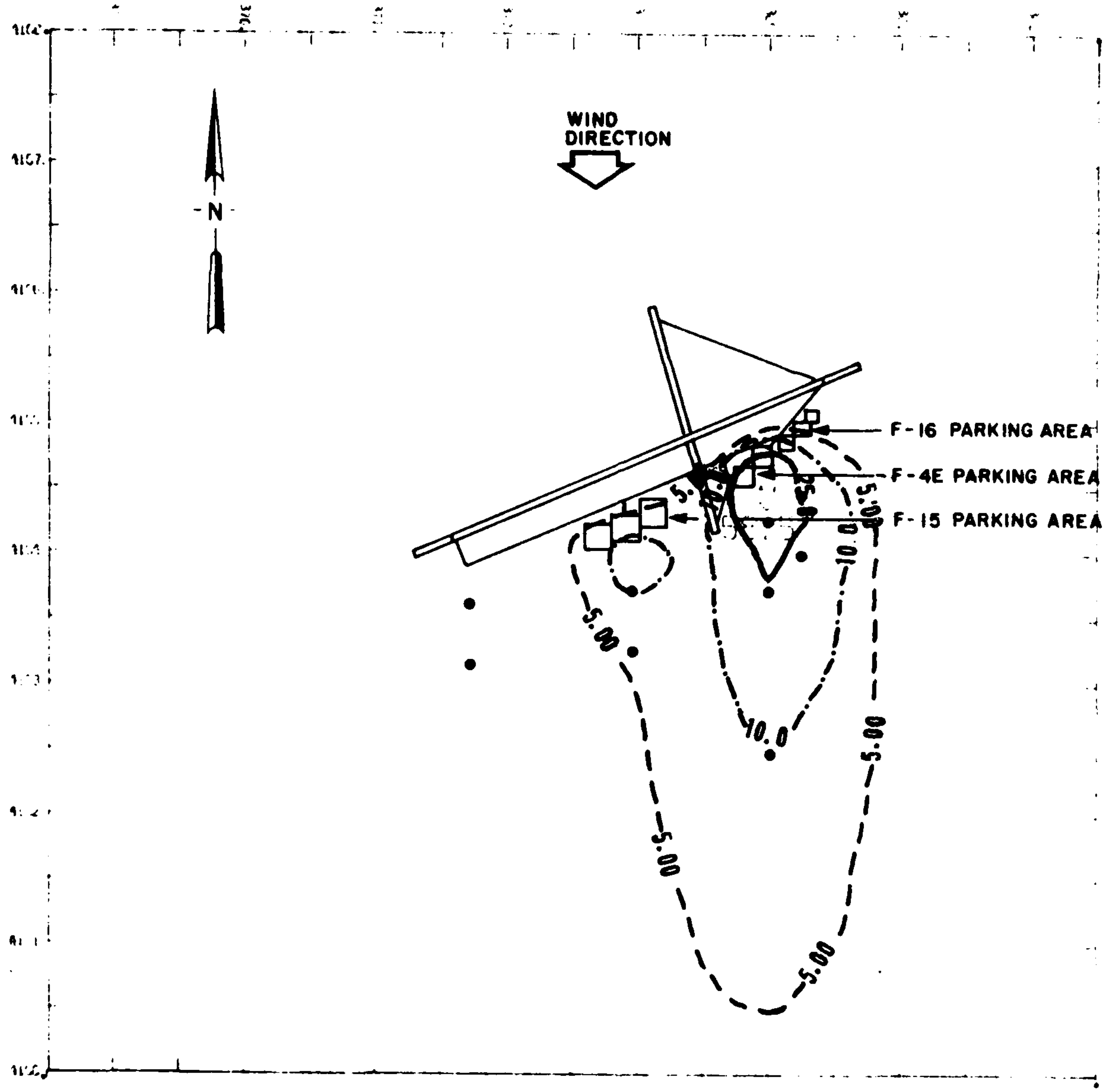

Figure 13. HC Isopleth (Aircraft)

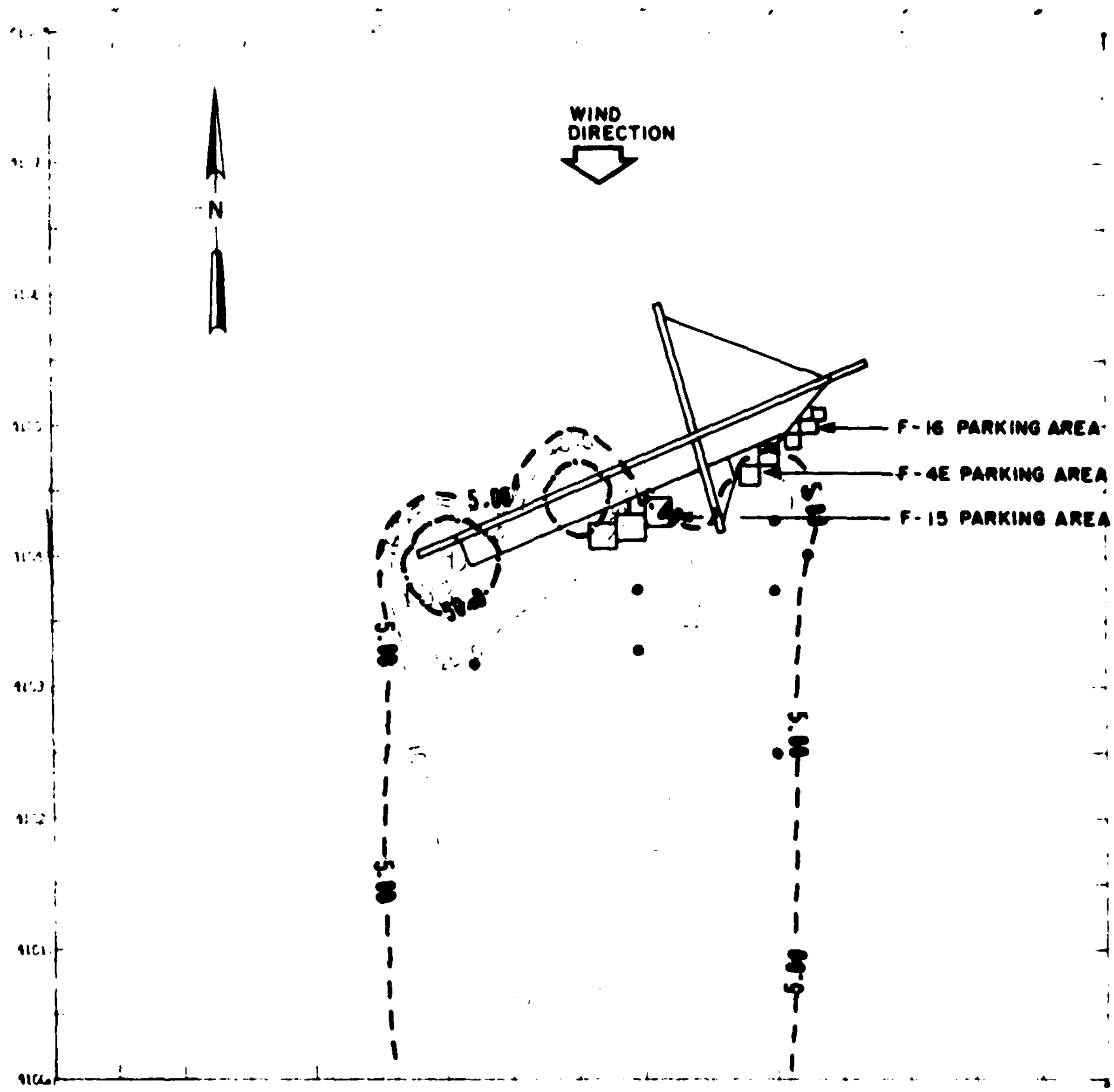

Figure 14. NO_x Isopleth (Aircraft)

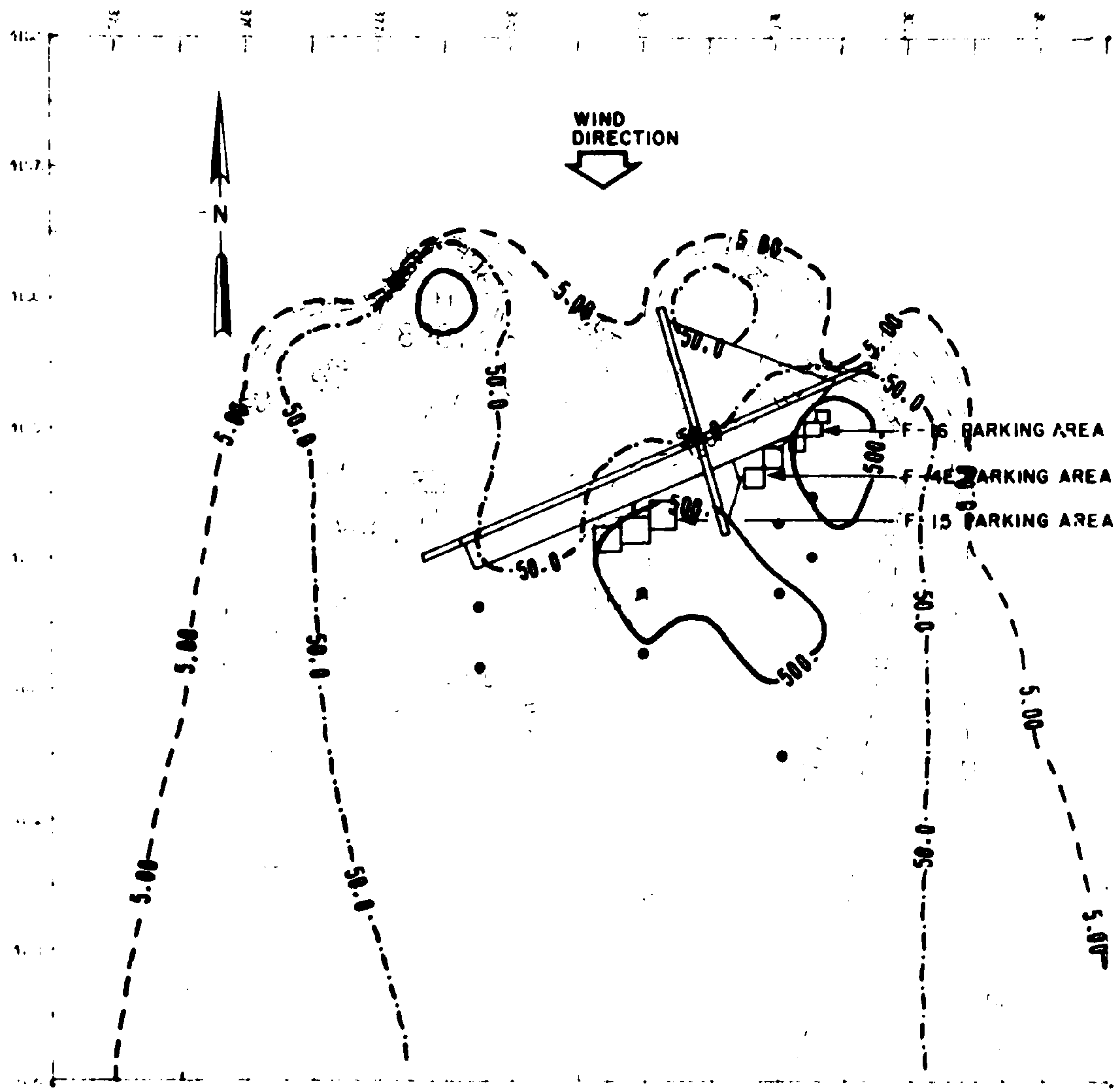

Figure 15. CO Isopleth (Base)

TABLE 6. POLLUTION CONCENTRATIONS AT SPECIAL RECEPTORS ($\mu g/m^3$)

RECEPTOR SOURCE	DOWNWIND DIST. FROM SOURCE (km)	CO			HC			NO_x			PM			SO_x		
		JP-4	JP-8	W C	JP-4	JP-8	W C	JP-4	JP-8	W C	JP-4	JP-8	W C	JP-4	JP-3	W C
F-4E PARKING AREA	0.5	344	353	364	41	43	46	10	11	11	3	3	3	2	5	13
	1.0	178	183	188	22	23	24	7	7	8	2	2	2	1	3	7
F-15 PARKING AREA	0.5	106	112	118	9	10	11	19	19	20	1	1	1	2	4	11
	1.0	56	60	63	5	6	6	15	16	16	1	1	1	1	3	7
F-16 PARKING AREA	0.5	23	24	26	2	3	3	3	3	3	1	1	1	1	1	2
	1.0	12	13	14	1	2	2	2	2	2	1	1	1	1	1	1
BLAST AREA	0.5	20	21	22	2	2	3	65	67	69	2	2	2	4	7	21
	1.0	10	10	11	1	1	1	28	28	30	1	1	1	2	2	9
AVERAGE (AC)	0.5	51	53	54	6	6	7	6	6	6	1	1	1	1	1	3
(BASE)	1.0	143	143	143	50	50	50	37	37	37	298	298	298	315	315	315

relate short-term pollutant concentrations to adverse health effects. Each pollutant concentration is converted to PSI values by five linear segments. Segment breakpoints occur between 100 and 500. They relate to the NAAQS, three levels of Federal Episode Criteria and the Significant Harm Levels. Several modifications are made to the PSI for the purpose of this study. The California NO_x standard of 470 g/m^3 is assigned the 100 PSI value since a short-term NAAQS does not exist. The NAAQS HC level of 160 g/m^3 is given a 100 PSI value because hydrocarbon does not have a direct health effect but can be a precuror to photo chemical oxididants. AQAM one-hour concentration results had to be coverted to the appropriate time period with power laws (Reference 14). Although this conversion does not account for parameters such as atmospheric stability and downwind distances, the accuracy should not affect the results. The PSI are calculated for the AQAM predicted concentrations at the special receptors. These receptors are located where most of the support personnel work. the worst case PSI results are presented in Figures 16 and 17. The 0.5 km receptor (Figure 16) predicts the maximum aircraft PSIs while the 2.5 km receptor predicts the aircraft PSIs at the base boundaries and quarters. All aircraft related PSIs are compared to the base PSIs at the AQAM receptor point.

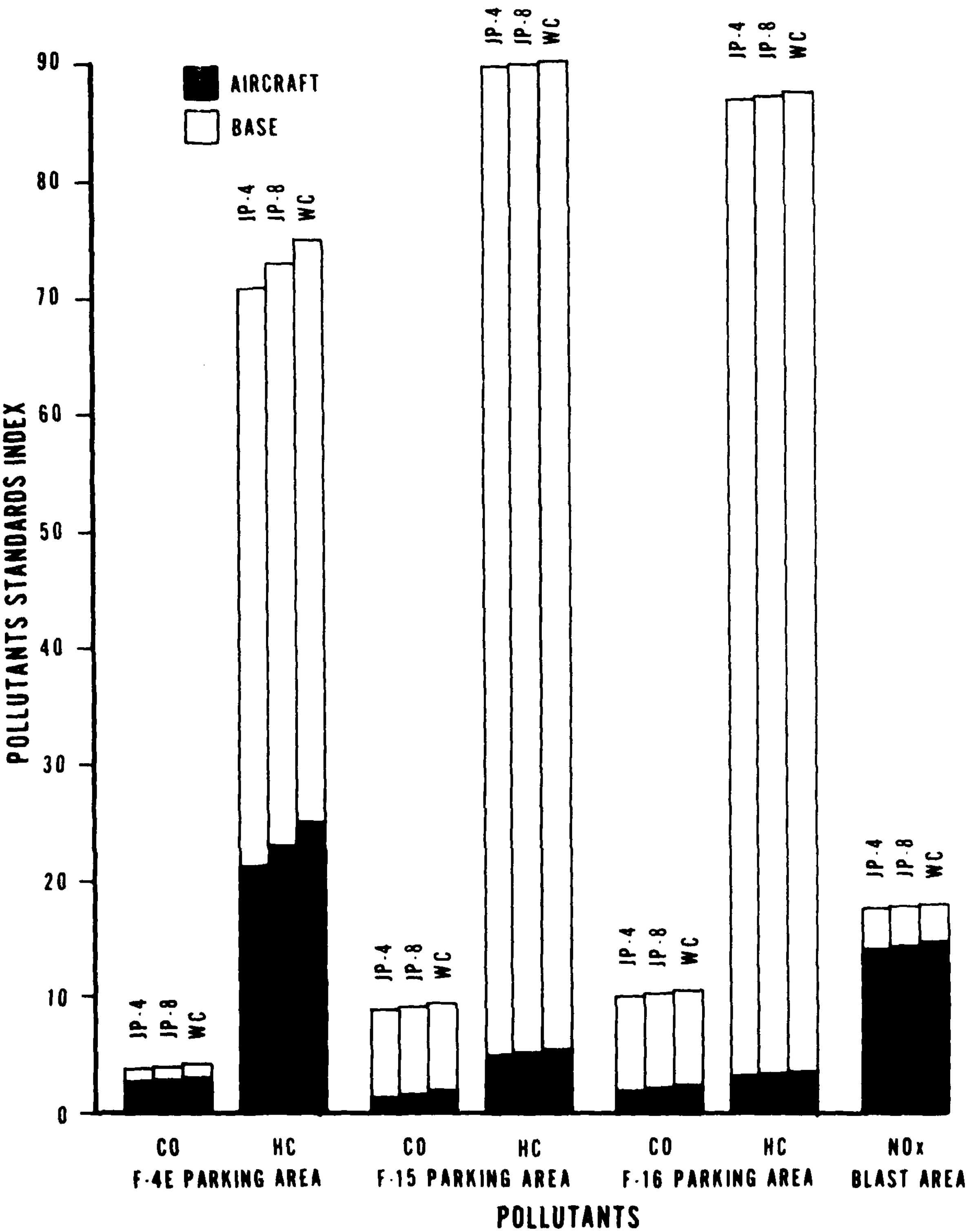

Figure 16. Aircraft Source PSIs

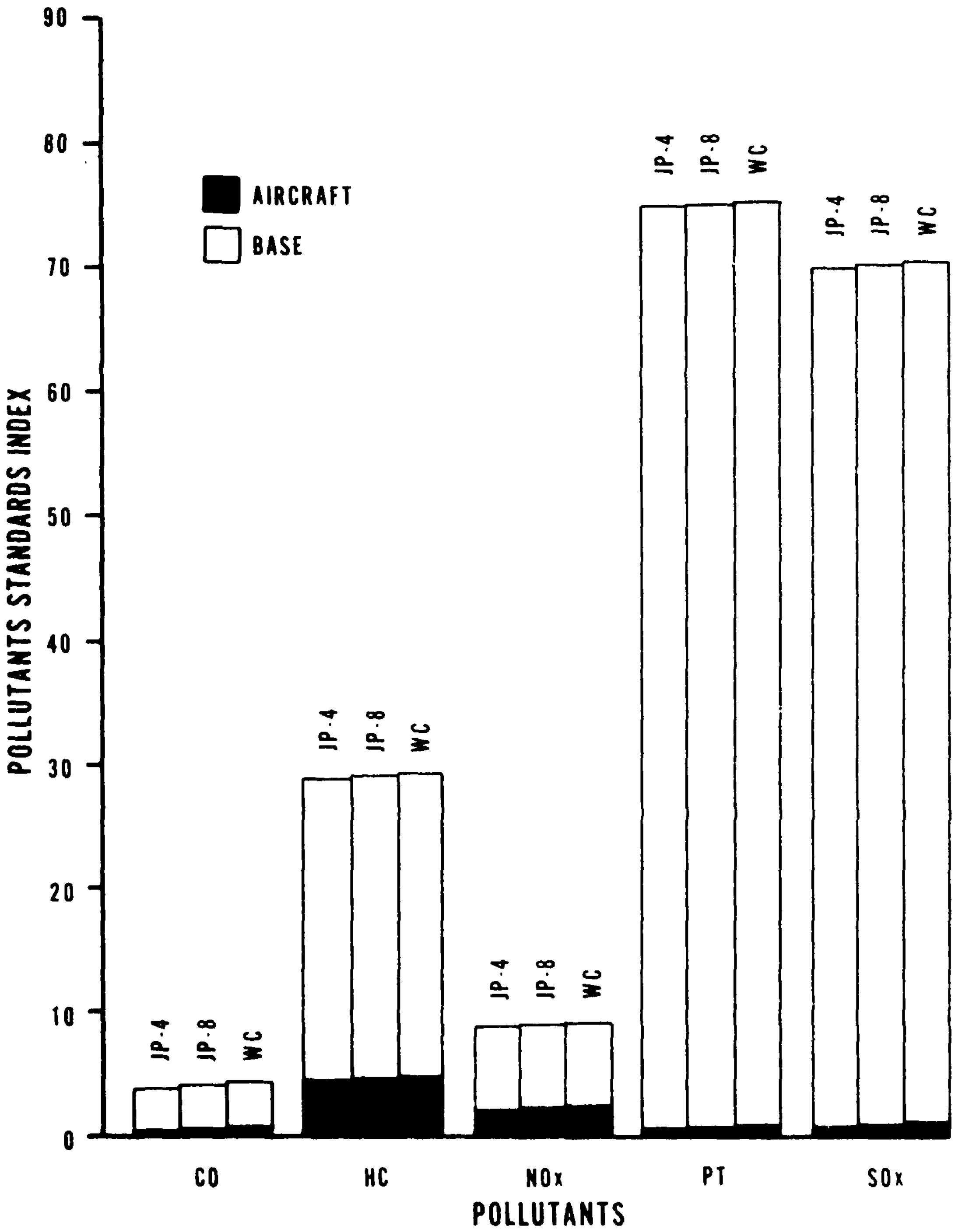

Figure 17. Average Base PSIs

SECTION V

RESULTS

5.1 EMISSIONS ANALYSIS

An effective alternative aviation fuel assessment methodology has been developed using the AQAM computer program. The alternative fuel preprocessor program structure enables AQAM to compute emissions and concentrations from many different fuel properties. AQAM generates a variety of outputs that are useful in determining the air quality impact from base operations. LTO emissions are one of the outputs. The relationship between fuel properties and AQAM predicted LTO emissions are presented in Figures 7 through 10. These figures can be used to compare different aircraft types or calculate annual airbase aircraft emissions from the fuel properties. For example, a fuel property is specified and the appropriate pollutant emission factor is obtained from the figures. The number of annual air base LTO cycles are multiplied by the emission factor to calculate the annual pollutant emissions. Air Force bases usually report their operations in LTOs. The fuel property versus LTO emission charts can be generated for any turbine with alternative fuel emission measurements.

Emission measurements are currently available for the J79 and F101 turbine engines. For the F-4E, F-15 and F-16 aircraft powered by these engines, all alternative fuel blends LTO emissions increased over the baseline JP-4 fuel except for SO_x. Fuels 8 and 10 had a lower fuel sulfur content than JP-4. The aircraft LTO emissions ranges are shown in Figure 18. The greatest increases in LTO emissions occurred for CO and SO_x. The percent increase in aircraft CO emissions is 10 percent, 35 percent and 30 percent for the F-4E, F-15 and F-16, respectively. Although the F-15 and F-16 emission increases are much greater than the F-4E, their LTO CO emissions are approximately half of the F-4E. Sulfur emissions are in direct proportion to the fuel sulfur content. Sulfur content of the fuels examined varied by almost an order of magnitude. The highest and lowest reported J79 engine HC emission rates were used to compute the range. The HC LTO emissions vary only 20 percent. The variations in F-15 and F-16 HC and PM LTO emissions increased slightly over the JP-4 baseline fuel. Overall, only CO and SO_2 emissions increased significantly with fuel blend.

The evaporative hydrocarbon emissions caused by the alternative fuel blends was analyzed with the AQAM inventory program. The evaporative hydrocarbon emissions from fuel storage decreased for all fuel blends examined. Representative fuels are presented in Table 5. Fuel 1 is the baseline JP-4 fuel. Fuel 8 is a blend of JP-4. Fuel 2 is JP-8 and fuel 4 is a JP-8 blend. Fuel 13 is the ERBS fuel. The AQAM predicted annual breathing loss emissions from fuels 2, 4, and 13 are approximately one-third less

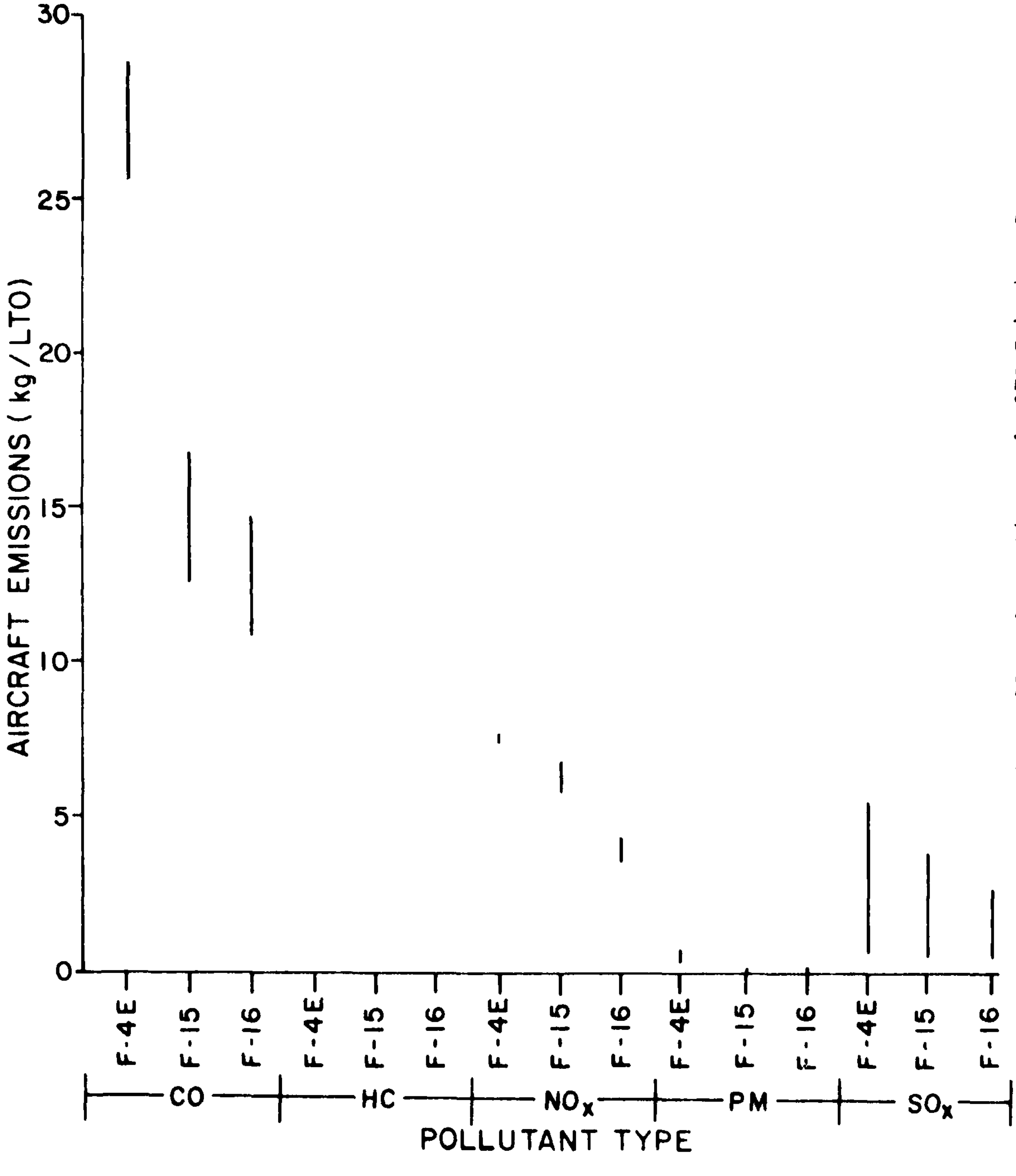

Figure 18. Alternative Fuels LTO Emissions Ranges

than the JP-4 baseline fuel. These fuels have vapor pressures less than one-sixth that of JP-4. Fuel 8 being a JP-4 blend has a higher vapor pressure than the other fuels. Thus, the evaporative hydrocarbon emission reduction is not as great.

The hydrocarbon emissions from annual aircraft operations in the base vicinity are also presented in Table 5. The total HC annual emissions are shown along with the aircraft and the venting and spillage HC emissions. Fuels 2, 4, and 13 reduced venting and spillage HC emissions and cause a net decrease in total aircraft operation emissions even though the aircraft emissions increased. This is not the case for fuel blend 8. F-4E hydrocarbon emission rates were the highest for this fuel - almost 50 percent higher than the baseline JP-4 emission rate at idle. A net increase in annual emissions is predicted because of the greater F-4E aircraft emissions. However, if the F-15 and F-16 were the only aircraft at the base, there would be a net decrease in annual aircraft operation HC emissions.

The predicted total base annual HC emissions for each fuel are tabulated in Table 5. All alternative fuels reduced overall annual base hydrocarbon emissions although the JP-4 blend hydrocarbon reduction is not as great. The overall alternative fuel HC reduction is not a "one for one" tradeoff since base motor vehicle and stationary sources make up almost 60 percent of total HC emissions. Aircraft emissions account for approximately 6 percent and breathing losses for 34 percent of total HC emissions.

5.2 AIR QUALITY ANALYSIS

Worst case 1-hour pollutant concentrations isopleths computed by the AQAM short-term program are presented in Figures 12 through 15. These concentrations result from aircraft operations with JP-4 fuel and include auxiliary ground support equipment, filling, spillage and venting emissions. The aircraft PM and SOx concentrations were 2 percent below the NAAQS and considered insignificant. The DF-2 and JP-8 concentrations increased only by 5 percent from the JP-4 baseline fuel CO, HC_x and NO_x concentrations.

The F-4E parking area is the greatest aircraft source of CO and HC emissions. Thus the F-4E concentrations are double the F-15 and F-16 parking area concentrations. These concentrations indicate the higher F101 combustion efficiencies when compared to the J79. The concentrations are extremely small when compared with the NAAQS and other base sources. Figures 15 and 16 are AQAM predicted CO concentration isopleths resulting from airbase sources other than aircraft operations. Aircraft concentrations are completely masked by the airbase concentrations. Motor vehicles contribute the greatest amount of emissions since the peak hour traffic conditions are being considered. The peak CO

concentrations correspond to the major parking facilities on the base.

The isopleths give a generalized representation of the concentration boundaries. However, the 0.5 km grid spacing can lead to misinterpretation of the concentrations because the isopleth is calculated by linear interpolation between the receptor points. A source on the receptor point will have a smaller concentration value than a source in between the receptor points. Maximum aircraft concentrations occur near the aircraft's exhaust port. These predicted concentrations are probably greater than actual concentration since plume rise is not predicted by the dispersion model. As discussed earlier, AQAM predicted concentrations from aircraft are reliable 0.5 to 1.0 km downwind from the aircraft.

AQAM receptors were located as indicated in Figure 11 to predict concentrations resulting from aircraft operations. The values are indicated in Table 6. All receptor pollutant concentrations were converted to PSI values and presented in Figures 16 and 17. The aircraft operations contribution is extremely small in terms of health effects, especially since these operations and meteorological conditions represent the highest emissions and least atmospheric dispersion of the aircraft pollutants. The worst case fuel increase the pollution concentrations approximately 5 percent and well below the NAAQS (100 PSI). When compared to the PSI values from other base sources, at the average receptor the aircraft pollution concentrations are only 5 percent of the base concentrations. These concentrations do not include background concentrations. The aircraft concentration variations are insignificant switching from JP-4 to the worst case fuel when airbase concentrations are included.

SECTION VI

CONCLUSIONS

The AQAM program can predict aircraft and base operation emissions from alternative fuel properties. The AQAM routines and techniques can analyze other turbine engines as data becomes available. Other fuel properties and characteristics can be added to the alternative fuel engine emission routines if required. AQAM also predicts the evaporative hydrocarbon emissions to facilitate the hydrocarbon trade-off between increased aircraft emissions and decreased evaporative emissions.

AQAM predicts the following for a tactical base aircraft operation:

(1) The F-15 and F-16 with the F101 turbine engine operations have an insignificant impact relative to the five major pollutants on local base air quality using JP-4 and the other alternative fuel blends.

(2) F-4E CO and HC emissions increased with some of the fuels. These increased CO and HC emissions could cause concentrations greater than short-term NAAQS in the near field "hot spot" (within 100 meters of the aircraft parking area). However, these concentrations beyond the "near field" will be below the standards.

(3) There exists a significant hydrocarbon evaporative emission reduction with the less volatile fuels such as the JP-8 blends and No. 2 diesel.

These conclusions are based on combustor rig data tests. There could be some minor changes in the results when full engine emissions are measured. However, as the new F-15 and F-16 aircraft and others with similar engine technology are implemented into the Air Force, aircraft air quality impacts from JP-4 and alternative fuels will be minimal. The F101 represents the type of engine that will be used in the 1990s when alternative fuels are being produced.

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